LIMITING ABNORMAL MOLD GROWTH IN BUILDINGS

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ABSTRACT

Studies show that mold, a fuzzy cob-web-like growth produced primarily on organic matter, is all around us. Molds typically begin their lives as dormant, airborne spores, but when they come into contact with moisture, a food source, and the right temperature range, they grow into living organisms which collectively are called colonies. They are a basic component of the natural ecosystem. Some molds, such as penicillin and yeast, are good, while others such as ringworm and athlete's foot, are not. Unfortunately, we are learning from studies of contemporary buildings that abnormal amounts of certain molds inside our buildings can adversely affect the health of humans and animals.

The same conditions that support mold growth also support fungal decay in wood, or rusting and corrosion of metals. Abnormal mold or fungal growth, then, can create major problems for building owners. Moisture is the key factor that building designers and owners can manage in order to limit mold growth. This paper introduces some of the types of molds that are found in buildings, the physical parameters of growth, what the suspected effects are on humans and animals, and ways to limit the moisture they must have to grow. The paper concludes with suggestions for designing, constructing and maintaining buildings to minimize the potential for mold growth.

INTRODUCTION

Conditions Precedent for Mold Growth

The reader should note that this paper focuses on mold in buildings. However, a discussion of mold is not complete without discussions of fungi, a type of mold that leads to biodegradation in wood and wood products, because the conditions under which they grow are similar.

The basic developmental unit of all filamentous fungi, common in the wood components of our buildings, is the "hypha," a cell which, unlike the cells found in plants and animals, polarizes all of its growth at one end so as to form elongated filaments (Singh 1994, p. 59). The materials for growth of the hyphae are taken up from the surface or from within the material upon which the hyphae are growing, or are transported from other parts of the mycelium (multi-cellular structures of hyphae). Sometimes the fungal structures observed are referred to as "fruit bodies," and are seen as mushroom-like structures. At other times they may be observed as mold fibers. Collections of fungi are referred to as "colonies." In summary, building materials will suffer from fungal growth when conditions develop in or on them that resemble the natural environmental niche in which the fungus has evolved to live in nature. "Fungal spores are ubiquitous and will colonize parts of a building where conditions become suitable" (op.cit., p. 74). A food source (e.g. wood), a compatible living environment (e.g. moisture and temperature), and a source (e.g. fungal spores, which are ubiquitous) must come together in a building situation for mold to grow on surfaces, or decay of wood, to be observed.

Figure 1 shows the basic components necessary for mold growth on building materials. The mold spores grow on a substrate building material. Moisture is supplied to the mold spores from any one or more of the following sources: moisture in the air, condensation on surfaces, or interstitial water wicked through the porous substrate material. The temperature and humidity in the environment must also be within the growth parameters of the particular species of mold to grow.

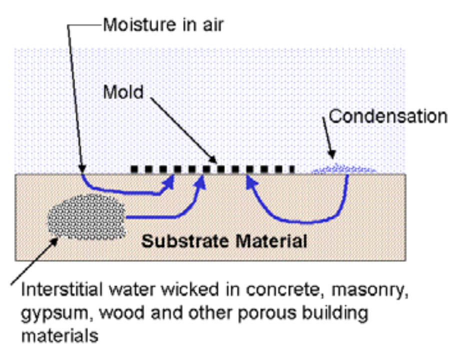

Figure 1. Physical Requirements for Mold Growth

Optimal Conditions for Mold Growth

Fungi may differ in their optimum temperature for growth or activity, but for most of those that live in wood, the optimum temperature range is 68º-86º F (20º-30º C). Mold in buildings, however, may grow well beyond the optimal temperature ranges. Table 1 shows that some molds can live in temperatures as low as 41^0 F (<5^0C), and as high as 127^0F (53^0C). The American Society of Heating and Refrigerating and Air-Conditioning Engineers (2000), suggests that the optimal range of relative humidity in buildings be in the range of 40-60%. Recent recommendations by the Environmental Protection Agency suggests that relative humidity levels in the range of 30-50% would be better, because molds do not grow as readily at humidity levels below about 55% (http://www.epa.gov/iaq/molds/prevention.html).

Table 1. Mold and Temperature Relationships

	Optimum			Limits				
Species	°F	°C	A_w	°F (Lower)	°F (Upper)	°C (Lower)	°C (Upper)	A_w
Aspergillus amstelodami	91	33	0.93	50	108	10	42	0.71
Aspergillus niger	91	33	>0.98	54	109	12	43	0.78
Aspergillus Gumigatus	104	40	>0.97	54	127	12	53	0.82
Penicillium martensil	73	23	>0.98	<41	90	<5	32	0.79
P. Islandicum	88	31	>0.97	50	100	10	38	0.83
Stachybotrys atra	73	23	>0.98	45	99	7	37	0.94

Note: A_w is the straight ratio of the vapor pressures.
Sometimes this is referred to as "water activity" level.
For example, an A_w of 0.8 is the same as the equilibrium RH of 80%.
Table adapted from:
http://www.iaqsystems.com/feature_articles/controlling_mold_growth_in_exterior_walls_of_buildings_03.htm

Mold in Buildings

A lengthy discussion of all the molds that may be found in buildings, and what they look like, will not be covered here. However, it is instructive to look at one of the more prevalent molds. Stachybotrys chartarum, sometimes called Stachybotrys atra, is a rather toxic mold that produces mycotoxins that can adversely affect human health. This mold is often found in the presence of other molds.

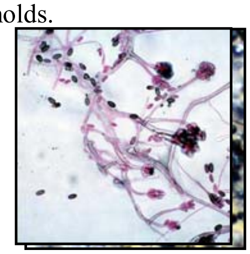

Figure 2. Stachybotrys Mold
Source:
http://www.dehs.umn.edu/iaq/fungus/stachybotrys/

Figure 2 (left photo) shows the Stachybotrys mold and its finger-like hyphae under the mircroscope. The picture at the right shows Stachybotrys in a petri dish in a laboratory. The exact mold species in Figure 3 is unknown, but the photo shows the extent to which mold growth can occur in buildings. Table 1 contains an abbreviated list of some of the more common molds found in buildings. Table 2 contains a brief listing of some of the common health effects of molds.

Figure 3. Extensive Mold Growth in a Building
Source: http://www.epa.gov/iaq/molds/intro.html

Table 2. Common Health Effects of Molds

Potential Health Effects Associated with Inhalation Exposure to Molds and Mycotoxins

- Allergic Reactions (e.g., rhinitis and dermatitis or skin rash)
- Asthma
- Hypersensitivity Pneumonitis
- Other Immunologic Effects

Research on mold and health effects is ongoing. This list is not intended to be all-inclusive.

The health effects listed above are well documented in humans. Evidence for other health effects in humans is less substantial and is primarily based on case reports or occupational studies.

Source:
http://www.epa.gov/iaq/molds/append_b_2.html

Following is a more detailed description of the health effects of molds. These are provided at the Environmental Protection Agency's website (http://www.epa.gov/iaq/molds/append_b_2.html):

"Allergic Reactions.

Inhaling or touching mold or mold spores may cause allergic reactions in sensitive individuals. Allergic reactions to mold are common. These reactions can be immediate or delayed. Allergic responses include hay fever-type symptoms, such as sneezing, runny nose, red eyes, and skin rash (dermatitis). Mold spores and fragments can produce allergic reactions in sensitive individuals regardless of whether the mold is dead or alive. Repeated or single exposure to mold or mold spores may cause previously non-sensitive individuals to become sensitive. Repeated exposure has the potential to increase sensitivity.

Asthma.

Molds can trigger asthma attacks in persons who are allergic (sensitized) to molds. The irritants produced by molds may also worsen asthma in non-allergic (non-sensitized) people.

Hypersensitivity Pneumonitis.

Hypersensitivity pneumonitis may develop following either short-term (acute) or long-term (chronic) exposure to molds. The disease resembles bacterial pneumonia and is uncommon.

Irritant Effects.

Mold exposure can cause irritation of the eyes, skin, nose, throat, and lungs, and sometimes can create a burning sensation in these areas.

Opportunistic Infections.

People with weakened immune systems (i.e., immune-compromised or immune-suppressed individuals) may be more vulnerable to infections by molds (as well as more vulnerable than healthy persons to mold toxins). *Aspergillus fumigatus*, for example, has been known to infect the lungs of immune-compromised individuals. These individuals inhale the mold spores which then start growing in their lungs. *Trichoderma* has also been known to infect immune-compromised children.

Healthy individuals are usually not vulnerable to opportunistic infections from airborne mold exposure. However, molds can cause common skin diseases, such as athlete's foot, as well as other infections such as yeast infections (March 30, 2002)."

MOISTURE IN BUILDING MATERIALS

Moisture migration in building materials is considered to be hydraulic, under the influence of hydrostatic forces when the materials are saturated, and as a vapor flow produced by the vapor pressure differences in unsaturated materials. The interactions between water molecules and the materials they pass through, such as salts, and electrical potentials, may affect the moisture migration.

Materials exposed to excess moisture may experience a variety of undesirable problems. Rot in wood is a biological phenomenon where the excess moisture supports the growth of fungi that destroy the wood fibers. The moisture content (MC) in percent by weight at which rot occurs in most species of wood is about 20% MC (ASHRAE 1997). At moisture contents of 20% or greater, rot or decay of wood is a major concern because, given enough time and the right conditions of temperature and humidity, wood framing members will lose their structural capacity and therefore their ability to support their own weight and anything attached to them.

Corrosion, supported by moisture on metals, is essentially a process of chemical or electro-chemical decomposition. Metals are often used in the construction of buildings for structural supports, or as fasteners of the various structural components. They are also used for wiring, piping, and air delivery systems to provide mechanical services. Corrosion of these components shortens their service life. In the worst case, extensive corrosion can lead to life safety or structural safety problems.

Moisture comes in three forms: as vapor, as liquid, and as ice. In any of these physical states, moisture can cause damage to building materials. Increasing the amount of moisture in hygroscopic (porous and deleterious) materials causes their dimensions to increase in the directions of the x, y and z axes. The reverse is also true: reducing the moisture in materials causes them to shrink in all three directions. Freezing of water in materials causes the greatest increases in dimensions, relatively speaking. Repeated cycles of moisture-induced shrinking and swelling in building materials leads to rapid physical deterioration.

Moisture Leakage in Building Envelopes

Water penetration into the perimeter walls of buildings in the Southern states along the Atlantic Seaboard and the Gulf of Mexico, where rainfall rates are high and humidity levels and temperatures remain high for most of the year, is a constant problem for building owners. In recent years, reports of damage to building components, including rot of wood framing and corrosion of metal framing and fasteners, have increased dramatically. For example, numerous reports of water-related problems with buildings clad with exterior insulation and finish systems (EIFS), and the recent litigation against many of the EIFS and hardboard siding manufacturers, has made building designers reconsider their approach to designing the building envelope to increase the durability of the building materials being used.

A study of eighteen EIFS-clad buildings (seventeen residences and one church) in Houston, Texas (a hot-humid climate); Chicago, Illinois (a moderate-damp lakeside climate); and, Denver, Colorado (a dry, temperate climate) found the highest levels of trapped moisture in the walls of buildings in Chicago. The mean MC in Chicago was 19.37%. Denver was second, with an average moisture content in the sheathing behind the insulation board of the EIFS of 18.85%. Houston was third with average moisture contents behind the EIFS of 14.74% (Graham 1999). Every building tested during this study was leaking water, and the majority had leaks that introduced enough water to rot the wood framing supporting their cladding.

Water-related problems with EIFS in over 300 homes in the Wilmington, North Carolina area were reported by the NAHB Research Center in 1996, and before that in the same area by the Wilmington Section of the American Institute of Architects (1995). In the NAHB study, EIFS-clad houses two to six years of age indicated deterioration of the wood structural members, caused by water leakage into the wall systems. The primary cause of moisture accumulation in the walls was rainwater intrusion from a combination of factors including:

- Improper sealing of joints at windows, doors and other openings and penetrations;
- Improperly sloped EIFS surfaces;
- Inadequate flashing at roof lines, dormers, decks, fireplace chases, etc; and,
- Window frames that leaked water into wall cavities.

The leakage mechanisms identified by the NAHB Research Center's EIFS Task Force were troublesome because the EIFS trapped the rainwater in the walls where it caused damage to the structural and other components of the building. The polystyrene insulation board of the EIFS blocked the water from evaporating on the exterior of the building, and the moisture barrier on the inside of the walls blocked it from evaporating towards the interior of the building. The water remained stored in the wood framing, batts insulation, wall sheathing, and gypsum wallboard long enough for damage to occur to these materials.

The U.S. Department of Housing and Urban Development conducted investigations of EIFS-clad properties financed with federal money and issued Bulletin No. 101, dated July 26, 1993. One of the new requirements of Bulletin 101 was prohibition of gypsum sheathing as a substrate behind EIFS claddings on HUD's properties. Water leakage caused the paper faces on the gypsum sheathing to delaminate or deteriorate, releasing the cladding fastened to it.

RESEARCH METHODOLOGY

Field Inspections

The fundamental problem that lead to this research was to find the causes of water-related damage to building envelopes in the United States. Over 5,000 buildings have been inspected in over 15 states, but the subjects of this report were the buildings inspected in the states bordering on the Gulf of Mexico and the South Atlantic seaboard. Approximately 4,000 buildings were inspected in North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana and Texas during the period of 1995-99. Buildings were also inspected in Tennessee and Kentucky, areas with climates that closely resemble the Gulf states because of their high rainfall rates and temperate climates. Most of these buildings were inspected in support of research or investigations in support of litigation involving hard board siding, EIFS, brick or other siding materials.

The Council for Masonry Research, made up of representatives of the masonry industry in the United States, also funded a controlled study of buildings in Houston, Texas; Denver, Colorado; and Chicago, Illinois (Graham 1999). Five single-family properties in the Houston, Texas area and one home in the Plano, Texas area were inspected during the summer of 1997.

A detailed sampling procedure following the recommendations included in a report entitled "Moisture Assessment Guidelines," by the NAHB Research Center (Appendix A, 1996) and modified by the author (Graham 1997), was used on the home inspections in Texas. In these inspections, areas known to be leak-prone with EIFS claddings from the NAHB Research Center studies in Wilmington, North Carolina, were tested, as well as at least ten statistically random locations on each building. In this fashion both statistically non-random and random locations were tested.

In addition to the detailed home inspections in Texas, during the same period approximately 30 buildings, including commercial office buildings, hotels and shopping centers, were surveyed in the following cities which are located in states with hot-humid climates:

- Mobile, Alabama
- Orlando, Florida
- Pensacola, Florida
- Austin, Texas
- San Antonio, Texas
- Gulfport, Mississippi
- Washington, DC

The inspections of the above commercial buildings did not utilize the destructive testing procedures recommended by the NAHB Research Center. Instead, these inspections were performed with field observations and photographic recordings.

<u>Review of the Literature</u>

An extensive review of the literature on moisture problems in building envelopes was also conducted to gain as much knowledge as possible about the causes of, and solutions to, such problems. The literature review included analyses of works from laboratory-based research projects and field investigations in the United States, Canada, and a number of countries in Western Europe. Contacts were made with laboratories in these areas to see what kinds of moisture research were underway in the institutions of higher learning, or in government and industry laboratories.

<u>Computer Simulations</u>

In addition to the literature review and field investigations, Moist, Release 3.0 (NIST 1997) software was run on the microcomputer to analyze different kinds of wall assemblies to model moisture contents in and drying of building materials over time. These analyses were compared with the results of the field investigations and with theoretical information on moisture performance in building materials to check for consistency in the data.

<u>Data Analysis</u>

The research plan was to compare the data from all of the sources to see if there was a chain of evidence that would be consistent with the hypothesis that damage to building materials in the building envelopes inspected, either in this research or by others, was caused by water infiltration. Robert Yin (1984) has discussed the use of a case study research methodology where the investigator wants to know the "who," "what," "where," "how" and "why" about a situation. The case study research methodology is also appropriate when the investigator has no way of applying an experimental treatment to subjects or when the research cannot be conducted in the controlled environment of a laboratory.

With case study research methods the correct way to draw conclusions about the findings is to refer the findings and conclusions back to the basic theoretical precepts upon which the hypotheses or propositions are based. The investigator looks at all of the data available from all sources to see if they are consistent. The goal is to use the widest possible range of sources of information to see if a pattern of evidence exists. This comparison of findings from different sources of information establishes the chain of evidence that Robert K. Yin (1984, 80) says is necessary to draw conclusions back to the original hypotheses or propositions, or possibly to populations that contain members similar to the case study subjects. The investigator must be cautious about using the results of case studies to imply or infer similar conclusions and recommendations to populations, however, unless they have characteristics similar to the case study subjects.

The following sources of information about moisture infiltration problems in building envelopes were reviewed for patterns of evidence:

- Review of investigations by others such as the NAHB Research Center, the American Institute of Architects, and the U.S. Department of Housing and Urban Development;
- Review of literature from educational institutions, government laboratories, and industry laboratories in the United States, Canada, and countries in Western Europe;
- Detailed field investigations of six buildings in Houston and Plano, Texas, using *in situ* testing protocols developed by the NAHB Research Center (1996) and by Graham (1997);

- Detailed visual inspections of approximately thirty buildings in cities of the Gulf Coast States; and,
- Visual observation of over 4,000 residential and commercial buildings in the same Gulf Coast States.

EXTERIOR WALL DESIGNS

The literature review found that there are four basic approaches to designing exterior walls for buildings. These are:

1. The surface barrier design;
2. The drainage plane design (sometimes called the *vented* design);
3. The drainage plane design incorporating the rainscreen principle (sometimes called a *pressure-equalized* or *ventilated design*); and,
4. The mass storage wall design.

The first three approaches to wall designs are common to the U.S. building industry. The fourth approach, the mass storage design, is used primarily in Europe. It will be described herein, but no buildings incorporating the mass storage approach were found during the field investigation phase of this research.

In the United States, the two most prevalent exterior wall finishes that incorporate the surface barrier design are wood sidings (including hard board and cement fiber board sidings), and exterior insulation and finish systems (EIFS). The primary design criteria for a surface barrier wall is that all water from rainfall or other sources must be kept on the exterior of the cladding system. No water can be allowed to get behind the exterior materials in the surface barrier design (Iano 1991, 18-20). With this approach, the goal for the building envelope, including all the openings in it for doors, windows, piping, wiring etc. is that it must be sealed to a watertight condition and kept that way for the life of the building. For illustrative purposes, Figure 4 shows the components of the surface barrier type of exterior insulation and finish system.

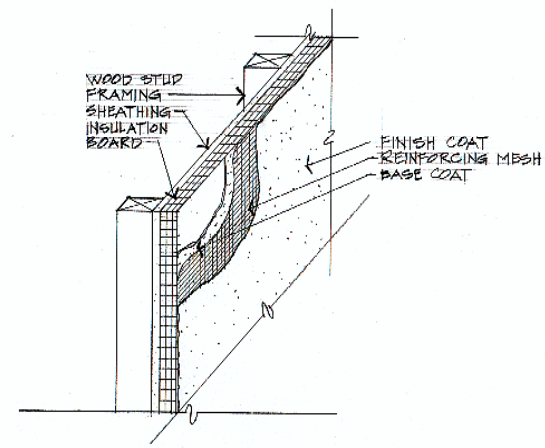

Figure 4. Components of a Surface Barrier Wall Incorporating EIFS

The drainage plane design (sometimes called a *drainwall or vented wall design*) incorporates a moisture retarding film or barrier between the cladding and the substrate upon which it is affixed. Channels, grooves or air spaces are typically provided on the backside of the cladding system to allow any water leakage that gets past the cladding a route back to the exterior of the wall. Weep holes and flashings at the bases of walls help to divert water leakage back to the exterior (Nelson and Waltz, 1996).

The drainage plane consists of a moisture barrier, such as felt paper, which is applied behind the cladding. Wood and hardboard sidings with shiplaps almost always include a drainage plane behind them, especially in the hot-humid climates, for redundancy in case water leakage occurs in the outer cladding of the envelope. Even with the drainage plane for redundancy, every effort is made with laps, sealants, and metal flashing pieces to keep water on the outside of the wall. It is a good system for wood or hardboard siding because every effort should be made to keep water from getting behind these materials. Wood and wood-based cladding materials are hygroscopic (porous) and they contain cellulose. They will deteriorate from the fungal growth supported by a constant source of excessive moisture.

A number of EIFS manufacturers have recently begun to offer their products with the drainage planes (Reicherts 1996). Figure 5 shows an EIFS design incorporating a drainage plane.

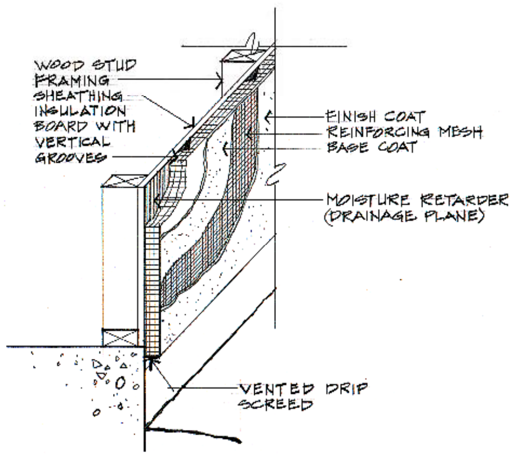

Figure 5. Drainage Plane Design EIFS

The third type of system is a drainage plane design incorporating the rain screen principle. These are sometime called *pressure-equalized or ventilated designs*. There are three predominant features of walls that incorporate the rain screen principle. These systems have the exterior face (the rain screen); the pressure-equalized cavity, and a waterproof air barrier system. The rain screen is the first line of defense in the wall cladding for keeping water out of the building. However, the operational assumption in designing this type of wall is acknowledgement that minute amounts of water will eventually get past the rain screen. This water is collected and routed directly to the exterior of the building before it can harm the building's internal components.

The pressure-equalized cavity, a component of the rain screen system, is responsible for the ventilation necessary to balance the wind-induced pressure differentials between the outside of the rain screen and the interior components of the wall system. This "shock absorber" mechanism helps to reduce the potential for wind-driven rain to enter the wall behind the outer cladding by releasing air at the top and bottom of the walls. Rainwater that gets past the rain screen drops out of the air in the cavity. The cavity, with the aid of the waterproof barrier and flashing, directs any water leakage back to the exterior of the building.

The waterproof barrier system (drainage plane) provides the redundancy necessary to keep air and water leakage that may occur from entering the interior of the wall. Drainage plane designs incorporating the rain screen principle have been provided in commercial construction in the United States for a number of years, but recent research in Canada has brought it to the foreground as a redundant system for EIFS installations on residential and commercial building construction (Canadian Home Builders Association 1997; and Day 1994, 34-35). Figure 6 shows the drainage plane design EIFS incorporating the rain screen principle. This design approach can be used for other siding materials such as vinyl, aluminum, glass, pre-cast concrete, and masonry.

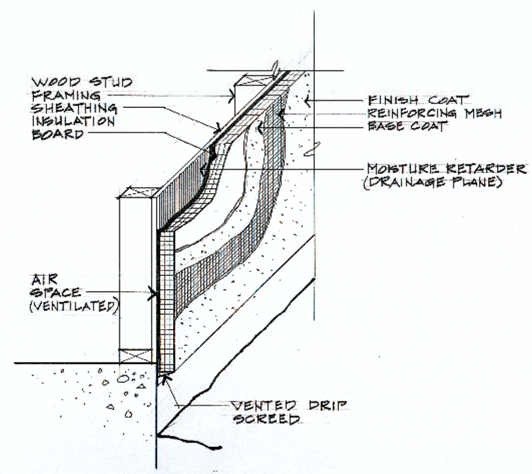

Figure 6. Drainage Plane Design EIFS with a Rain Screen

One way of distinguishing the two drainage plane designs is that the drainage plane design is vented at the bottom of the wall to allow gravity discharge of water leakage back to the exterior. On the drainage plane design with a rain screen, the cavity is ventilated at the top and bottom of the wall. The difference in these two systems, then, is that by design one is "vented," while the other is "ventilated." As noted previously, to date the majority of the EIFS installations in the United States have been surface barrier systems. Both drain wall designs have been introduced into the U.S. market during the past five years (EIMA 1997).

The fourth system is what is referred to here as the mass storage wall design. The mass storage system incorporates a surface barrier design with high quality control during application. The primary difference in the mass storage design as used in Europe, and the surface barrier design as used in the

U.S., is that the mass storage system used in Europe incorporates masonry or concrete substrates instead of the gypsum board, plywood, or oriented strand board substrates of the surface barrier design in the United States.

In mass storage wall systems, it is expected that some water or moisture will get past the surface coatings, but that such moisture will be in such minute quantities that it can be stored by absorption in the concrete or masonry substrates, which are usually quite thick (8” – 12” is common). This water will be allowed to evaporate back to the exterior, be collected in the cores or cavities incorporated in the masonry, or be drained to the base of the wall from gravitational forces and be diverted to the exterior with the use of flashings and weeps.

Because the masonry and concrete substrates are non-deleterious in nature, the presence of water in them does not support growth of rot-inducing fungi, or attract destructive insects such as termites or carpenter ants as readily as it does in wood. Freeze-thaw and other problems may occur, but experience has shown that the water storage capacity of these wall systems helps to alleviate the problems that occur when water leaks into walls framed with wood materials. The experience in Europe with mass storage wall designs has been that they perform well under service conditions, as long as water leakage is limited to minute amounts. Figure 7 shows the components of a mass storage wall design.

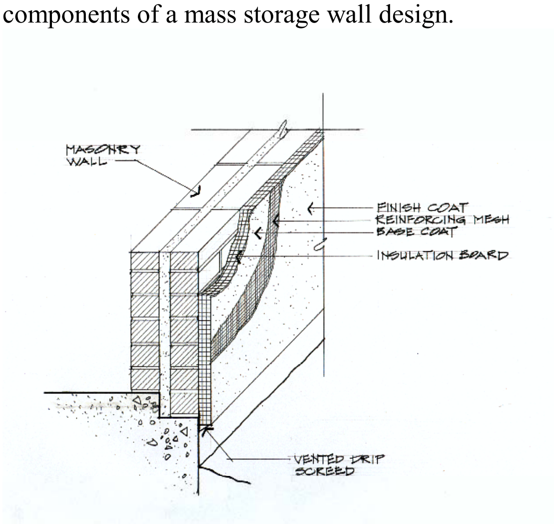

Figure 7. Mass Storage Wall Design EIFS with Masonry Substrate

FINDINGS FROM FIELD INVESTIGATIONS

Joseph Iano (1991) has noted that “A prudent assumption is that a wall will always admit some water, and many assemblies are designed to capture moisture and redirect it back to the outside” p. 18). Kevin Day (1994), an executive with one of the EIFS manufacturers in Canada, has acknowledged that “…water infiltration into an exterior cladding is inevitable. Hence, a means of drainage must be provided, and more importantly, the venting to allow this drainage must be designed to balance the pressure between the interior and exterior of the wall assembly” (p. 34).

The chain of evidence found in this study supports the proposition that surface barrier wall designs without drainage planes or moisture barriers behind their outer claddings will allow leakage to damage structural components behind the claddings in hot-humid climates. While an extensive review of the failure mechanisms will not be provided here, two examples from the field investigations will serve to demonstrate the value of drainage planes behind claddings.

Figure 8 shows what happens when water gets past the rain screen of a surface barrier design wall cladding that does not have a drainage plane or moisture barrier behind it. In this case, a surface barrier EIFS was installed on the building. Water that got behind the insulation boards was absorbed in the gypsum board wall sheathing. Eventually the gypsum sheathing deteriorated, and the supporting wood framing rotted as shown. Obviously, this level of decay greatly reduces the structural capacity of a building.

Figure 8. Example of Extensive Decay of Wood Framing

Figure 9. Mold Growth in the Interstitial Cavity of a Wall

CONCLUSIONS AND RECOMMENDATIONS

New Building Material Beak-in

The field research found that building designers need to pay attention to the requirement to release moisture in new building materials once a building is closed in and the mechanical systems are maintaining the thermal comfort. Most all new building materials give off moisture. Concrete, for example, is delivered to the jobsite in a liquid state with a large quantity of water in it. Framing lumber with moisture content of up to 19% is allowed by the codes. Paints, adhesives and other components are normally applied in a liquid state.

The building designer must keep in mind that these materials will give off moisture for several months once the building is occupied. Some provision must be made to dispel this moisture, either to the interior of the building so that it can be carried away mechanically, or into the atmosphere on the exterior. Trapping this moisture in crawl spaces under buildings, in the walls, or in the attic can cause serious problems for the building owner, as it can take months for the materials to reach equilibrium with their service environment. In hot-humid climates, this can be long enough to support mold growth on surfaces, or rot in framing.

Wall Design Principles

The data shows that there are a number of recommendations, which, if followed, would greatly improve the performance of cladding systems on the walls of buildings in the hot-humid climate around the Gulf of Mexico and Southeastern Atlantic Seaboard. It is apparent from many past studies and the field investigations of this study that failure to provide redundancy for leakage on the building envelope is a major drawback for surface barrier cladding materials. There is a high statistical probability that water leakage will occur somewhere, at some time, on the envelope of almost all buildings in locations with high rainfall rates.

A surface barrier cladding design without a redundant moisture management system has a high probability of failure. This loss of redundancy exacerbates the potential for problems when materials such as oriented strand board sheathing, plywood sheathing, gypsum sheathing, wood framing, steel stud framing, and the fasteners for all of these materials, are subjected to repetitive water leakage over a period of time.

From an architectural perspective, identification of failure mechanisms gives architects, engineers, contractors, and building owners information they can use to improve the performance of cladding systems. Many of the failures or problems with surface barrier claddings discovered in this research emphasize the need to efficiently and effectively manage water in its various forms at the outer surfaces of the building envelope. This is true for any cladding system, but is especially critical for a surface barrier EIFS without a drainage plane. All of the findings from the literature reviews and from the field investigations were consistent on this point.

Figure 10 shows a recommended wall design for proper water management in locations with the hot-humid climate. There are essentially three sources of moisture that must be accounted for by the wall designer and provisions to manage all of these are shown in the figure.

As note above, a method of escape must be provided for the moisture in new building materials. This moisture must diffuse to either the outside or the inside of the wall. In the design shown in Figure 7, the majority of this moisture will diffuse to the interior of the building.

Another form of moisture that must be accounted for in the hot-humid climate is indoor humidity during the heating season of the year (winter). Even in the hot-humid climate, some moisture will be driven by vapor pressure differentials from inside the building into the interior of the wall during the heating season. This vapor moisture is usually present in very minute amounts and can be stopped if a vapor diffusion retarder film stops its advance just behind the finish materials on the inside of the wall. The finishes on the gypsum, such as paint or vinyl wallpaper, must be slightly permeable, however, to allow diffusion of such moisture to occur towards the interior spaces of the building when the relative humidity inside the building is lowered by mechanical means.

The third, and perhaps most critical source of moisture in this study of exterior wall finishes is the moisture – liquid or vapor - that can get behind the cladding on the building envelope from physical or air leakage. In Figure 10, a cavity is recommended for venting the leaked water or vapor moisture to the exterior. A drainage plane is provided at the back of the cavity to stop any moisture from getting into the sheathing or other structural components of the wall. Liquid moisture in the wall or vapor moisture being driven by pressure differentials from the outside of the wall (higher temperature) towards the interior of the wall (lower temperature) during the cooling season of the year will be blocked by this drainage plane.

Wood, plywood, hardboard or other decay prone sidings should be designed initially as surface barrier rain screens to keep water out of the cavity space. It is always a good practice to try to achieve a water tight rain screen at the surface of the wall in a hot-humid climate location with its high rainfall rates. A drainage plane behind the cladding will provide the redundancy necessary for building owners to achieve good service life from the walls on their buildings even if the rain screen fails at some point during the life of their building.

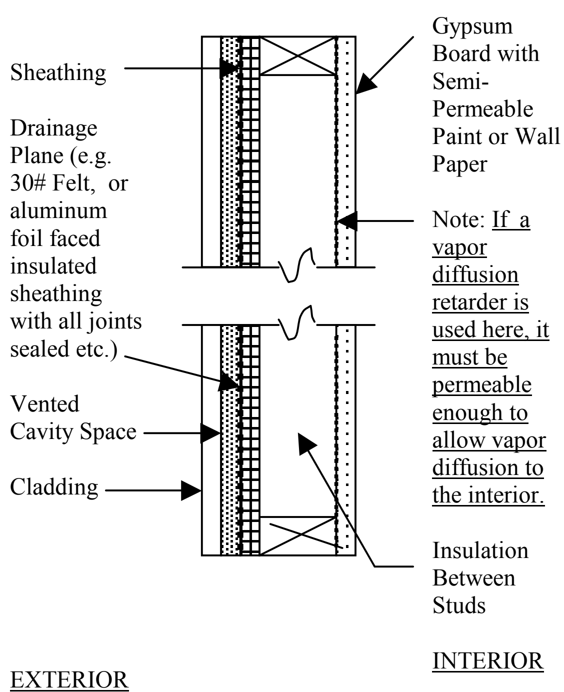

Figure 10. Recommended Wall Design for Redundant Water Management in the Hot-Humid Climate

HVAC Design Recommendations

Another common design problem that is under the architect and mechanical engineer's control is the amount of static pressure placed on the building (Graham 1997b). Contemporary air conditioning standards for buildings require that the building envelope be airtight in order to be energy efficient. A goal, in terms of moisture management at the building enclosure, is to use the heating, ventilating and air conditioning (HVAC) system to provide some positive pressure on the building envelope to keep vapor moisture or free water from being sucked into through the cracks and holes in the building envelope. In the warm, humid southern states, the amount of outside air provided into the delivered air stream, and how much humidity it contains, is a very real concern to the building owner. The outside air must be minimized to the amount that will provide some positive pressure on the building and yet meet code requirements, but the outside air that is brought in to do this must be pre-conditioned to remove most of the moisture it contains.

When the air is not preconditioned, the main cooling coils of the air conditioning units often have a problem removing all of the moisture from the air, delivering high levels of humidity indoors. The resulting high indoor humidity levels may then support condensation on materials, as well as the growth of mold. This discussion should also be expanded to include air quality (IAQ) issues as research suggests. How much positive pressure to provide on the building envelope is part of the mechanical engineering design that should comply with building code requirements and ASHRAE standards. As noted above, the EPA now recommends that indoor relative humidity levels be limited to the range of 30-50%.

In summary, there are steps architects, engineers, contractors, and owners can take to minimize the potential for moisture-induced mold and fungal growth in buildings. Adherence to a few fundamental principles of building design, construction and maintenance that have been developed over the centuries can pay big dividends in the form of increased durability of materials, improved performance of mechanical systems, and improved indoor air quality.

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